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THE ROLE OF SIMULATION IN HIGH TECHNOLOGY
MISSILE APPLICATIONS

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model and simulation realism and credibility. A summary highlights key points contained in this document.

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I. SIMULATION OBJECTIVES AND BENEFITS

A. INTRODUCTION

The acquisition and operation of quality, affordable high-technology weapons require effective test and evaluation support over the entire life cycle of weapon systems. Defense Department procedures for acquiring and supporting complex weapon systems establish compressed schedules and key milestones at which programmatic and technical decisions must be made. An increasingly important and valuable source of reliable information for program managers and decision makers is high-fidelity weapon system simulation which, in a controlled setting, replicates system operation and the physical effects which influence system performance. High-fidelity simulation can result in an improved understanding of system behavior and thus can become a cost-effective management and engineering tool.

A program manager's objective is to develop, produce, and field an affordable system that meets established mission performance requirements. The introduction of high technology into military weapon systems has severely complicated the attainment of this objective and has led to the utilization of sophisticated simulation to assure the effective and affordable application of high technology. A frequent criticism of deployed systems is that they do not reliably perform as promised, are not operationally available for adequate periods of time, and are difficult to maintain once they fail. These shortcomings are a direct result of the failure to acquire and apply a sound understanding of system behavior during the acquisition and operation support phases. This has led to a growing disenchantment in the user community for high technology and to an argument for simpler, cheaper systems in large quantities. To follow this rationale would be to reduce U.S. forces to pursuing a one-on-one strategy which would be foolhardy in light of the numerical advantage of Soviet forces. High-fidelity simulation can help program managers successfully deal with the demands placed on them by the complexity of high-technology systems. Simulation is a rapidly developing technology itself and is being employed as an increasingly important means of measuring and evaluating the performance of advanced systems. High-fidelity simulation can help assure that a weapon system meets its design specifications and mission requirements with allocated resources.

The Advanced Simulation Center (ASC) of the U.S. Army Missile Command at Redstone Arsenal, Alabama, provides high-fidelity simulation services to the defense community. The ASC has been the pioneering facility in performing simulation of flight hardware, missile sensors, and guidance and control components. Current capabilities are oriented toward missile system simulation, but the long-range goal of the ASC is to simulate an entire weapon system and to evaluate its performance. The realistic environment of high-fidelity simulation provides credible data which reduce

the risk and uncertainty in system performance and thus improves decision making throughout the missile system life cycle. The ultimate benefit from effective simulation is the knowledge that a quality, affordable product has been fielded to successfully meet the intended mission need.

This document provides an overview of the ASC approach to missile system simulation, defines the role of simulation in relation to other methods of system performance evaluation, and presents the potential benefits to be derived from simulation support over the weapon system life cycle. The topics discussed include ASC philosophy and methodology, simulation capabilities, and the ASC management approach. This document also describes the ASC approach to environmental modeling and the verification and validation program which ensures both model and simulation realism and credibility. A summary highlights key points contained in this document.

B. MANAGEMENT AND TEST PHILOSOPHIES

The complexity of a missile system and its applications demand an appropriate and clearly defined management and test philosophy which will promote the realization of program objectives. Each program manager should be aware of the various available management and test philosophies and concepts and should have a fundamental appreciation of the nature of high technology. The selected philosophy must satisfy certain criteria. It should be systematic in nature and should facilitate a learning versus a grading approach to testing. The philosophical concept should foster the development of engineering confidence as opposed to statistical confidence and should be oriented toward an integrated life cycle view, allowing synergistic cooperation and interaction among developer, tester, and user communities. Because of varying program complexity, the selected concept should be tailored to the particular program technology and application and should recognize the need for realism in testing and the attendant requirement to demonstrate this realism. A program manager and his engineering staff must obtain meaningful data input for system evaluation. Realism in testing and simulation generally requires that fidelity be incorporated in the testing and simulation and in the models which drive them.

The defense community in government and industry must adapt effectively to the complexity and demands of high technology and its applications in sophisticated military weapon systems. A sound understanding of this high technology is clearly required to assure its effective and affordable application in new systems. An inadequate understanding of complex system behavior and applications has caused a systemic problem which originates in the improper selection of management and test philosophies for individual weapon systems. Because people are creatures of habit and tradition, they tend to follow familiar approaches and techniques; therefore, the current tendency is to manage and test complex weapon systems in the same way as earlier, simpler systems were managed and tested. Modern, more complex systems, however, generally necessitate new approaches and techniques. Systemic change is needed because the traditional approach based

upon flight testing is not affordable and can not provide the sound understanding and insight required to realize the program objectives for a complex weapon system. The critical action is the selection of an appropriate management and test philosophy which will enable the development of in-depth understanding of system behavior and therefore assure the effective and affordable application of high technology.

The traditional program management and test philosophy and concept, *incremental testing*, is oriented toward an incremental buildup of confidence by testing system components and subsequently integrating these into increasingly higher levels of the system. This philosophy depends on a large number of varied flight tests. The cost of this particular approach and its difficulty in providing timely, sufficient, and meaningful management and technical input have created problems for the program manager and his engineering staff with respect to developing and fielding high-technology systems. Since the traditional approach has proven inadequate, another performance evaluation approach must be followed. Of the available approaches, high-fidelity simulation offers the potential to satisfy this pressing need.

The accelerating current trend is toward a management and testing philosophy referred to as *all-up testing*. This philosophy is similar to that used by the Apollo program, where extensive ground tests and high-fidelity simulations were performed and were complemented with a minimum number of actual flight tests. The approach was selected because of the tremendous complexity of the Apollo program itself. The basic orientation of *all-up testing* is that extensive ground tests and simulations are performed using dedicated missile hardware, coupled with a relatively small number of flight tests. Flight tests are reduced by up to 75% of those required for *incremental testing*. With the cost of an individual flight test approximating one million dollars, initial savings in a program of 100 flights could approach \$75 million (less the cost of simulation). Furthermore, the flight tests performed with *all-up testing* tend to have engineering test objectives which provide data to validate the results obtained from the ground tests and simulations.

Whatever management and test philosophy is selected, program managers should recognize that there is a hierarchy of performance evaluation methods and that no one method can satisfy all program needs and objectives. Therefore, the program manager should wisely select from the available methods and provide a balanced mix. The emphasis and the degree of utilization of any one method depends upon the program requirements associated with the sophistication of the technology and the applications of the weapon system. The objectives are to obtain significant savings to provide meaningful management and technical data input for improved decision making by developing an ability to understand complex system behavior and applications.

C. SYSTEM PERFORMANCE EVALUATION METHODS

The tools available to evaluate missile system performance are ranked in Figure 1 in order of increasing realism and complexity. *Combat* is the ultimate measure of system effectiveness. *Guided flight tests* can closely emulate reality; although in this method, a surrogate environment is typically substituted for an actual threat scenario. Realism vis-a-vis the threat is an issue which must be satisfactorily demonstrated before flight test predictions can be accepted with great confidence. In the remaining evaluation methods -- seeker-in-the-loop (SIL) simulation, captive flight tests, computer simulation, design analyses, and bench tests -- certain aspects of reality are replaced by models to gain scientific control over engagement scenarios and the large number of variables which can affect missile performance. Each method contributes to the overall understanding of system performance. *Bench tests* provide data regarding the behavior of individual hardware components. *Design analyses* predict the interaction of these subsystems. *Computer simulation* is an analytical tool for predicting overall system performance. *Captive flight tests* evaluate seeker hardware performance in flight, but without the correct dynamic effects of motion. *Seeker-in-the-loop simulation* provides a test bed for seeker hardware performance on a three-axis flight table in a controlled electromagnetic environment and includes the additional aspects of flight dynamics through computer models of the missile.

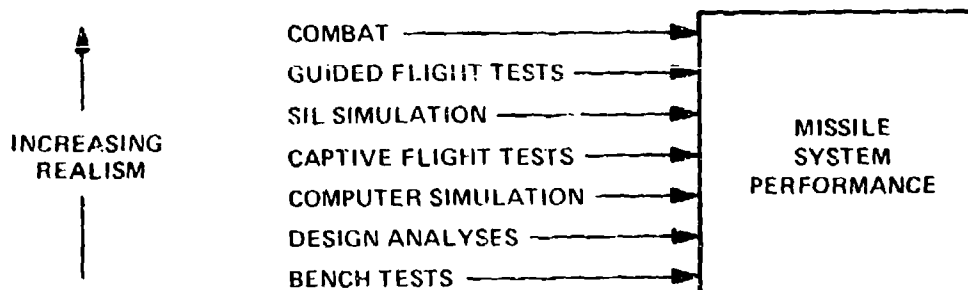


Figure 1. Hierarchy of Performance Evaluation Methods

Varying degrees of realism can be achieved within each performance evaluation category. Targets in flight tests can range from representative threats to ones with strongly augmented signatures to ensure missile guidance; environmental conditions can range from benign to adverse, with severe clutter and countermeasures. Similar degrees of realism can be obtained in seeker-in-the-loop simulations, captive flight tests, and computer simulations. In simulations as in flight tests, it is imperative that the appropriate degree of signature realism and environmental complexity be selected for the questions and scenarios under examination. Realism in performance evaluation generally requires increased complexity, greater cost, and longer development time,

whereas *excessive* fidelity wastes valuable resources. On the other hand, inadequate fidelity used to answer tough system questions provides meaningless answers which generally are misapplied.

The described performance evaluation methods should not be viewed as independent, but rather as constructively interacting modes contributing to an overall system test program. The controlled environment which can be achieved in laboratory and computer tests provides a valuable tool in both the planning and analysis of flight tests. Flight test data, in turn, can provide the benchmark against which the realism of simulation predictions can be judged. Similarly, a mature seeker-in-the-loop simulation developed as an integral element of the missile system procurement process can enhance combat performance by providing an operational tool in the development and refinement of battlefield tactics and a mechanism for quick reaction to changes in threat capabilities or characteristics. The proper role of simulation in the overall mix of performance evaluation methods is the subject of the next subsection.

D. ROLE OF SIMULATION

Many guided missiles currently in use or in development behave as complex non-linear mechanisms, both in their internal operation and in their dynamic electromagnetic interaction with targets, countermeasures, and the natural environment. This is especially true of the intelligent autonomous missiles now being developed. High-fidelity computer simulation of these systems has often proven to be too slow, costly, unwieldy, and uncertain for practical use as a systems analysis tool. Low-fidelity computer simulation is useful in defining operational constraints, but is too simplified to provide reliable answers to questions involving detailed subsystem interactions. Flight tests are too expensive for large-scale data collection, too overt for countermeasure evaluation, and too difficult to easily repeat. Therefore, the ASC has developed high-fidelity, seeker-in-the-loop simulation technology to augment the capabilities of computer simulation and flight testing and to provide an effective management and engineering tool for the analysis, development, testing, and operational support of missile guidance systems. High-fidelity simulation provides a cost-effective method to fill measurement and analysis voids and to provide responsive operational support.

Like computer simulation and flight tests, seeker-in-the-loop simulation requires a substantial initial investment in time, money, and manpower. Each new missile system has unique simulation requirements which demand careful planning and adequate development time. The best use of simulation resources is made when simulation capabilities evolve in conjunction with the missile system development process. As illustrated in Figure 2, the simulation is then available to provide answers to both routine and unanticipated questions which arise during the missile system life cycle. More importantly, as the simulation is validated during the system development process, confidence in predictions increases. A major decision, such as whether

or not to enter production, can be based largely upon simulation results only if the simulation provides a demonstrable correspondence to reality, i.e., only if it is validated.

The simulation realism necessary to predict flight test results cannot be achieved instantaneously, nor are the requirements for simulation realism the same throughout the missile system life cycle. During the early development stages when concept formulation, proof of concept, and source selection are dominant issues, relatively simple and straightforward simulation environments are often appropriate. During full-scale development and initial production, when system performance under adverse combat conditions must be demonstrated, much more complex environments are needed. The ability to simulate these complex environments provides a tool to measure system performance versus mission needs.

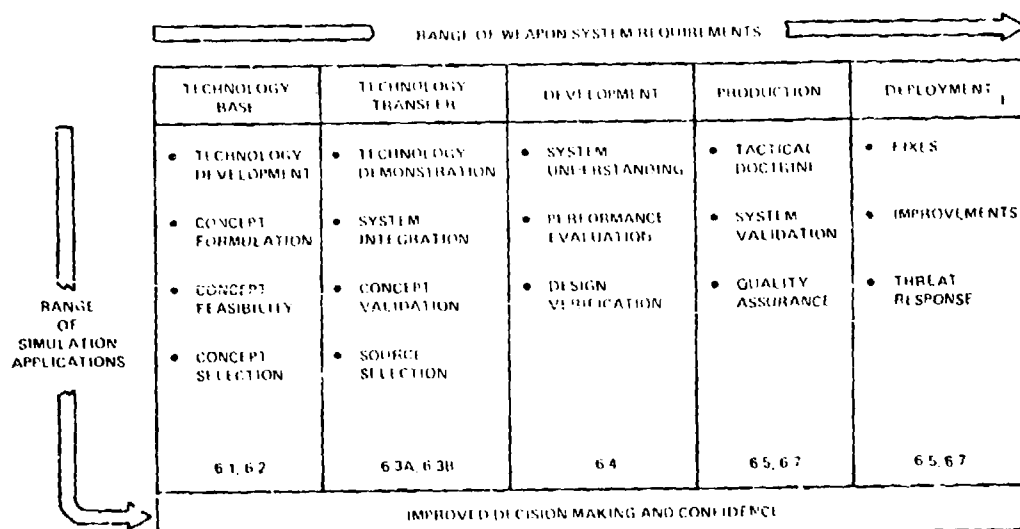


Figure 2. Role of Simulation During the Missile System Life Cycle

E. SIMULATION BENEFITS

Simulations provide technical and management benefits throughout all phases in the missile system life cycle. Each of these benefits is discussed below:

- Understanding -- High-fidelity seeker-in-the-loop simulation provides the ability to examine and measure the performance capabilities and limitations of complex systems by conducting controlled and repeatable experiments in a laboratory environment.

- Evaluation -- High-fidelity seeker-in-the-loop simulation at the ASC provides a dependable, independent Government evaluation tool to a program manager for his missile system. Complex, non-destructive experiments can be performed which are otherwise impossible or prohibitively expensive.
- Validation -- High-fidelity seeker-in-the-loop simulation is a unique, powerful method for validating missile performance capability against mission needs. Both developmental and operational tests are performed, providing improved confidence in system performance with an attendant reduction in program risk.
- Quality -- Life cycle simulation support exposes problem areas early in development, allowing early redesign. Repeated simulation runs provide reliability, availability, and maintainability (RAM) data; the simulation customer is provided with a better-fielded product because of validated performance in threat environments.
- Cost -- Significant reductions in overall program costs are achieved by utilizing seeker-in-the-loop simulation to reduce the number of flight tests.
- Time -- Initial program development time is reduced by providing extensive testing with limited hardware; design deficiencies are exposed early in the development cycle.
- Manpower -- Both Government and contractor manpower is saved as a result of the improved efficiency achieved by eliminating false starts, exposing deficiencies early, and correctly resolving complex technological issues.

In fact, improved quality and conservation of valuable resources are natural byproducts of utilizing seeker-in-the-loop simulation throughout the missile system life cycle. Without simulation, such system goals could be achieved only with a substantially increased investment. The following section provides a more detailed discussion of the ASC simulation philosophy and approach, which are structured to assure that all benefits of simulation are provided to the simulation customer.

11. SIMULATION TECHNOLOGY AT THE ASC

A. FACILITIES AND EXPERIENCE

Development of the ASC capability was initiated in the late 1960s in response to a MICOM mission requirement for an Army-wide source of expertise and capabilities in large-scale, seeker-in-the-loop simulations. Since activation in 1975, the ASC has developed over 150 large-scale, all-digital, hybrid, seeker-in-the-loop, and man-in-the-loop system simulations. The primary user has been MICOM, but users have included many other Army, Navy, and Air Force organizations. The ASC was established by the Army to provide high-fidelity simulations of guided missile systems and LCM hardware for the defense community. The facility performs simulations across a wide band of the electromagnetic spectrum, including radio frequency (RF) systems such as the HAWK air defense missile and the Advanced Medium Range Air-to-Air Missile (AMRAAM), infrared (IR) weapons such as CHAPARRAL and STINGER, and electro-optical (E-O) systems such as SPIKE and FUG-D. A full range of simulation services is available, including all-digital and hybrid (digital/analog) computer simulations, with particular emphasis on seeker-in-the-loop simulations in which missile seeker hardware is exercised dynamically at its proper electromagnetic operating frequency. As depicted in Figure 3, the seeker-in-the-loop facilities include three hardware simulators: the Radio Frequency Simulation System (RFSS), the InfraRed Simulation System (IRSS), and the ElectroOptical Simulation System (EOSS), which share a hybrid computer complex, the Advanced Simulation Processor, on which the effects of missile flight dynamics are modeled. Planned expansion of the ASC includes adding imaging infrared, multimode, millimeter, and additional RF capabilities.

B. ASC SIMULATION PHILOSOPHY

The simulation philosophy of the ASC is dominated by three major elements: (1) seeker hardware should be included in the simulation; (2) high-fidelity environmental models are critical for seeker-in-the-loop simulation realism; and (3) user participation is required for a successful simulation. To see how this philosophy is translated into concrete actions, consider the three major components in the assessment of guided missile performance: the flight dynamics system; the seeker, which includes both a sensor and a signal processor; and the electromagnetic environment. The computer modeling of the flight dynamics system, including missile components and their aerodynamic interaction with the atmosphere, is a relatively mature discipline which can be accomplished on the Advanced Simulation Processor with adequate fidelity, provided that established engineering techniques are properly employed. The seeker system, which provides guidance information to the flight dynamics system, is generally a complex non-linear device which is difficult to describe mathematically, as is its interaction with the third component -- the electromagnetic environment, which stimulates seeker response. Uncertainties associated with seeker modeling are avoided by utilizing seeker hardware in the simulation.

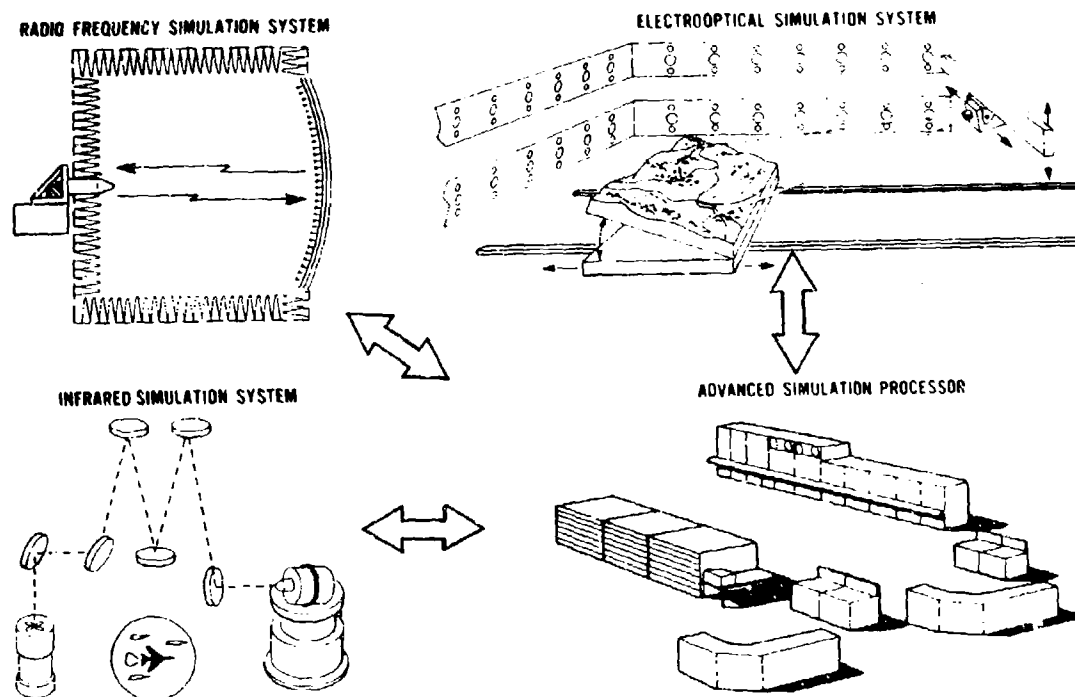


Figure 3. The ASC Simulation Facility

The electromagnetic environment is thus the critical element in achieving seeker-in-the-loop simulation realism. Great emphasis is placed in the ASC on the development, verified implementation, and validation of high-fidelity environmental models using independent measurements and flight test data. These models are developed in hierarchies of complexity, ranging from very simple to highly sophisticated. The selection of the appropriate fidelity models for an individual simulation program depends upon the application and sensitivities of the particular seeker under test. Model hierarchies allow the selection of the appropriate level of environmental complexity for each seeker and permit the determination of seeker sensitivity to elements of the environment through systematic variation of model parameters. Verification and validation of each simulation element is accomplished as a prerequisite to the verification and validation of the overall simulation.

The ASC philosophy includes customer participation as an essential factor in the success of its simulations. As a member of the simulation team, the customer provides program management insight and technical information for the system being simulated. He also must contribute to simulation planning

by helping to define simulation goals and objectives and the use to be made of simulation results. Detailed seeker operation and simulation goals and objectives are key factors in selecting the appropriate level of environmental model complexity. As illustrated in Figure 4, the selection of models more complex than is suitable for the intended scenario or application results in more time and cost than is required, while overly simple models result in simulation predictions which do not address the critical issues and encourage misapplication of results. The achievement of a cost-effective simulation whose results can be used with great confidence requires the level of environmental complexity appropriate for the scenario and application at hand.

The use which will be made of simulation results in the customer's decision-making process also is essential in determining the scope of the validation program which is appropriate for his simulation. When critical issues

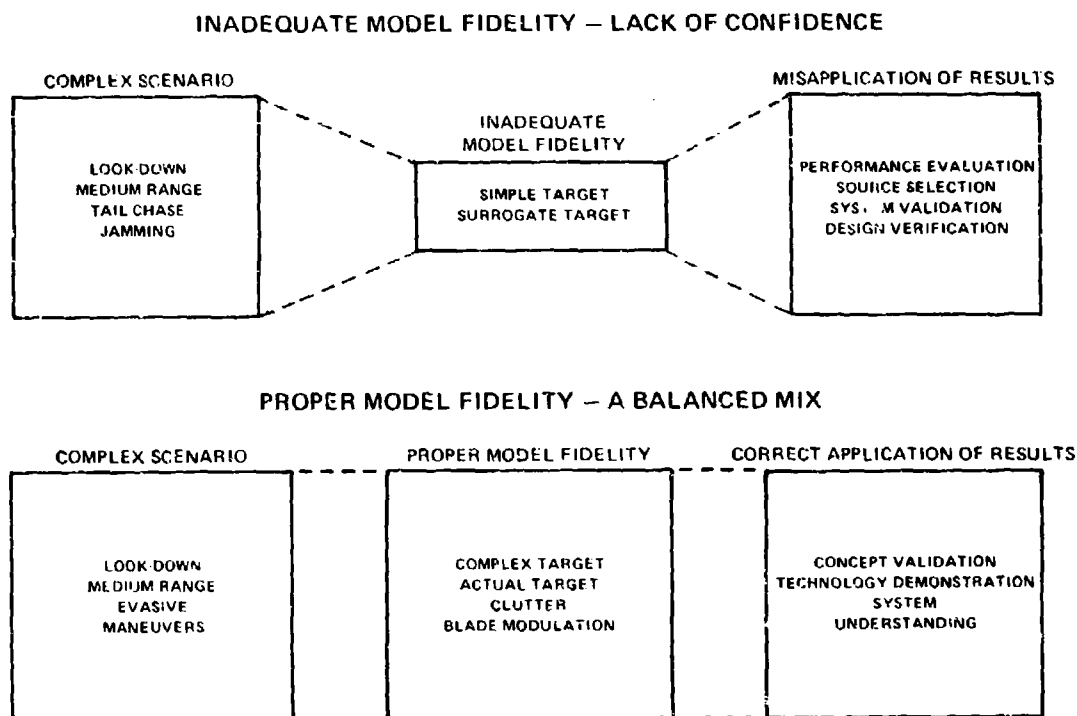


Figure 4. Importance of Proper Model Fidelity

are to be decided based upon simulation data, it is essential that the validity of this data be evaluated, for only then can the decision maker place the

proper level of confidence in the simulation results. Validation of both the environmental models and the overall simulation requires a commitment by the customer to provide the necessary independent data and resources to perform the validation assessments.

C. SIMULATION MANAGEMENT

The ASC has provided both computer and seeker-in-the-loop simulation support for a large number of RF, IR, and E-O systems. Within the RFSS facility, usage has been close to 100% capacity, with more than 50 major simulations being conducted during the first six years of operation. Simulations are funded by the user and scheduled to accommodate DoD program schedules and priorities.

A successful simulation requires that the customer and the ASC have a common definition of and agreement on simulation goals, objectives, and requirements. It is particularly important that the user be clearly aware of how simulation data and results will be used to make management decisions and resolve technical issues. To assure success, an ASC program is conducted in five phases:

- *Coordination and Planning* to establish goals, objectives, anticipated benefits, technical issues, and planned use of results.
- *Simulation Development* for preparation and implementation of environmental models, scenarios, software, interfaces, recording and display setups, and digital and/or hybrid missile models.
- *Simulation Verification* which integrates the facility simulation configuration with hardware and support equipment and verifies the overall simulation.
- *Simulation Operations* during which an average of 1000 to 3000 simulation runs may be made.
- *Validation, Analysis, and Documentation* which includes data collection, validation, reproduction, and distribution of simulation results.

III. ENVIRONMENTAL MODELING

A. MODELING PHILOSOPHY

A general methodology for environmental model development has evolved at the ASC. Models for specific features of the environment are developed in hierarchies of complexity and realism. The structure of the hierarchy ranges from a simple and straightforward representation of a particular phenomenon through a gradual increase in complexity to the most

sophisticated representation of an environment. The environment of an RF missile seeker, for example, includes radar returns from the desired target, other aircraft and airborne material, the earth's surface, and ECM emissions. Because of the complexity of the signals, an exact duplication of the real-world environment in seeker-in-the-loop simulations is clearly not possible. The objective of the RFSS environmental modeling effort is to ensure that the seeker is stimulated with signals which induce the same missile response as in an actual engagement. Modeling requirements are directly related to the seeker resolution in range, angle, power, and doppler; the engagement scenario; and the intelligence of the seeker processor.

The development of model hierarchies allows parametric analysis of the sensitivity of a given seeker to specific features of the environment. For example, the glint reduction capabilities of an RF seeker can be evaluated by first ascertaining performance against a non-glinting target and then successively adding glint of varying severity to determine how performance is affected. In this manner, system sensitivities are determined, response trends are isolated, and performance boundaries are established. The selection of the appropriate level of model complexity is based upon the specific goals, objectives and anticipated benefits for each customer.

Seeker-in-the-loop simulation also offers an ideal test bed for testing potential or actual ECM techniques. Using RFSS multiple target capability, a wide variety of jamming signals have been simulated from brute-force noise jamming to intelligent repeater jamming. Actual ECM hardware is preferred and normally used; however, models of jammer techniques are available. The purpose of the simulation may be to evaluate seeker ECCM capabilities or to develop ECM techniques against a threat-representative seeker. In either case, the ASC provides covert operation not available on a flight test range.

B. ENVIRONMENTAL MODEL VERIFICATION AND VALIDATION

It is crucial to the decision maker that simulation realism be evaluated by comparison with independent data. The ASC places great emphasis on the realism of the environment presented to the seeker under test because the credibility of the overall simulation hinges on this realism. In RFSS simulations, for example, environmental model validation is achieved by comparing seeker outputs generated during RFSS simulation runs with corresponding seeker outputs from flight tests. These validation comparisons are designed to quantitatively establish the degree of model realism and to define the regions and limitations of model validity. This information permits the decision maker to utilize simulation predictions in a more intelligent, better-informed manner.

The validation process can be viewed as building a pyramid of confidence in weapon system performance predictions. As new scenarios are

introduced, sensitivity analyses performed, models improved, and simulation predictions validated with flight test data and other independent analyses, the knowledge base of the pyramid is broadened and higher levels of confidence reached over a period of time. With simulation results supported by a carefully structured verification and validation foundation, engineers and program managers are able to make difficult missile system development decisions with increased confidence and decreased risk.

IV. SUMMARY

Simulation plays an important role during the entire missile system life cycle when properly integrated with other methods of system evaluation. To acquire an understanding of system behavior and to ensure an effective and affordable program while minimizing risk and uncertainty and building confidence in system performance, program managers should:

- Select and follow the test philosophy appropriate for their system.
- Recognize and provide a balanced mix of performance evaluation methods.
- Recognize the proper role of simulation.
- Invest the necessary resources in the simulation process.
- Investigate the full range of system applications and scenarios with increasing complexity and fidelity.
- Apply simulation throughout the weapon system life cycle.

The experience of the ASC in providing quality, high-fidelity simulation services to the defense community has demonstrated the importance of the following key simulation elements:

- Simulation realism is achieved by utilizing seeker and guidance electronics hardware in the simulation.
- Environmental models are crucial in achieving realistic seeker-in-the-loop missile guidance simulations.
- Models of the proper level of complexity must be selected based upon simulation objectives and seeker sophistication and applications.
- Verification and validation of the environmental models and the simulation are necessary for confident use of simulation results.

- Customer participation in defining goals, objectives, and requirements is essential to achieve a successful simulation.
- A simulation support program should evolve in conjunction with the missile system development program. Complexity is added as required, resulting in a mature simulation with the proper fidelity to support the fielded system.
- Key benefits of such a simulation support program encompass both management savings in resources and technical contributions to system understanding and effectiveness.

High-fidelity simulation is a powerful and necessary system development tool which provides a thorough understanding and characterization of system performance. Improved management control and technical decision making is possible due to the availability of reliable engineering data. The ultimate simulation benefit is a high-quality fielded product.

The following documentation is available for more detail on ASC capabilities and operational procedures:

1. *Radio Frequency Simulation System (RFSS) Users Guide*, RFSS-003-8, U.S. Army Missile Command, May 1979.
2. *Radio Frequency Simulation System (RFSS) Capabilities Summary*, Technical Report TJ-77-08, U.S. Army Missile Command, April 1977; revised July 1982.
3. *Verification and Validation of RF Environmental Models - Methodology Overview*, Technical Report RU-81-2, U.S. Army Missile Command, October 1980 (AU-AU99-324).
4. *RF Environmental Modeling in the Radio Frequency Simulation System*, Technical Report CR-81-3, U.S. Army Missile Command, May 1981.
5. *Missile System Simulation at the Advanced Simulation Center*, Technical Report RU-82-11, U.S. Army Missile Command, January 1982.
6. *The Advanced Simulation Center Brochure*, U.S. Army Missile Command.

Further information may be obtained by contacting:

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